N73-10283

NASA TECHNICAL NOTE

NASA TN D-6962

NASA TN D-6962

CASE FILE COPY

A GENERALIZED THEORY FOR THE DESIGN OF CONTRACTION CONES AND OTHER LOW-SPEED DUCTS

by Raymond L. Barger and John T. Bowen

Langley Research Center
Hampton, Va. 23365

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1972

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TN D-6962		

4. Title and Subtitle	5. Report Date
A GENERALIZED THEORY FOR THE DESIGN OF CONTRACTION CONES AND OTHER LOW-SPEED DUCTS	November 1972
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Raymond L. Barger and John T. Bowen	L-8448
	10. Work Unit No.
9. Performing Organization Name and Address	501-06-09-01
NASA Langley Research Center Hampton, Va. 23365	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Note
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A generalization of the Tsien method of contraction-cone design is described. The design velocity distribution is expressed in such a form that the required high-order derivatives can be obtained by recursion rather than by numerical or analytic differentiation. The method is applicable to the design of diffusers and converging-diverging ducts as well as contraction cones. The computer program is described and a FORTRAN listing of the program is provided.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Contraction cones Ducts Wind-tunnel design	Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	43	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

A GENERALIZED THEORY FOR THE DESIGN OF CONTRACTION CONES AND OTHER LOW-SPEED DUCTS

By Raymond L. Barger and John T. Bowen
Langley Research Center

SUMMARY

A generalization of the Tsien method of contraction-cone design is described. The design velocity distribution is expressed in such a form that the required high-order derivatives can be obtained by recursion rather than by numerical or analytic differentiation. The method is applicable to the design of diffusers and converging-diverging ducts as well as contraction cones. The computer program is described and a FORTRAN listing of the program is provided.

INTRODUCTION

For incompressible flows in ducts of slowly varying radius the one-dimensional flow relation between the velocity and the cross-sectional area can be used to predict the velocity distribution in a given duct or to design a duct for a desired velocity distribution.

However certain applications, such as the contraction cone for a wind tunnel, require short ducts with a relatively rapid variation of the wall radius. For such applications the one-dimensional relation no longer suffices, and a solution of the differential equation of the flow must be sought. Tsien (ref. 1) derived a solution for the stream function in terms of a prescribed axial velocity distribution, and applied this solution in the design of a wind-tunnel contraction cone.

It should be mentioned that such a design, obtained from the incompressible-flow equations, is a conservative design in the sense that when it is operated at off-design compressible conditions, the ratio of exit velocity to entering velocity is higher than the design ratio.

The major difficulty in applying Tsien's solution arises from the stringent requirements on the form of the input axial velocity distribution. These requirements are such that only a small class of functions can be used to describe the design velocity distribution. This problem has been considered in reference 2, where a form of velocity distribution different from that of reference 1 is used.

This form allows more freedom in shaping the design velocity function, but it introduces the problem of requiring hand calculations in analytic form of many derivatives of the function. Other analyses have utilized different formulations of the solution of the differential equation according to the way the variables are separated in solving the equation. The method of reference 3 assigns an exponential type of variation in the axial direction, and so is limited to a single design velocity distribution. References 4 and 5 use a periodic axial velocity distribution, but inasmuch as the flow is not periodic, this formulation gives rise to errors near the beginning and the exit of the contraction cone. An additional problem with this latter method is that the finite-term trigonometric approximation to a function is in general a function that oscillates about the desired function, and such a "wavy" distribution is not very satisfactory for design purposes. The three forms of solution for the stream function are given explicitly in reference 5.

The present analysis represents a generalization of the method of reference 1, in that a wide range of design velocity distributions is permitted so that the method is no longer restricted to a specific contraction cone but may be applied to the design of a wide variety of ducts. Greater accuracy is obtained through the use of an electronic computer and by retaining a large number of terms in the series solution.

SYMBOLS

A,B,c,d_n	arbitrary parameters and coefficients in expression for design velocity
$f_d = f_g - f_p$	
f_g	general form of design velocity distribution at centerline
f_p	preliminary form of design velocity distribution at centerline (eq. (3))
f_0	design velocity distribution at centerline used in reference 1
G	total velocity
H_n	nth Hermite polynomial
k	upper summation index
m,n	indices
x,r	cylindrical coordinates

u, v axial and radial velocity components, respectively

$z = cx$

δ_{mn} Kronecker delta

$\Phi = \frac{c}{\sqrt{\pi}} e^{-c^2x^2}$

ψ stream function

Subscripts:

i initial

f final

m,n indices

ANALYSIS

Tsien's solution (ref. 1) for the axial and radial velocities in incompressible axisymmetric flow is

$$u = \sum_{0}^{\infty} \frac{(-1)^n f_0^{(2n)}(x) r^{2n}}{2^{2n}(n!)^2}$$

$$v = \sum_{1}^{\infty} \frac{(-1)^n 2nr^{2n-1} f_0^{(2n-1)}(x)}{2^{2n}(n!)^2}$$

where $f_0(x)$ is the prescribed velocity on the axis. The stream function can be obtained by integration. Its k-term approximation is

$$\psi = \sum_{1}^{k} \frac{(-1)^{n-1} f_0^{(2n-2)}(x) r^{2n}}{2^{2n-1}n\left[(n-1)!\right]^2} \tag{1}$$

The kind of functions $f_0(x)$ which are appropriate for describing the axial velocity distribution will now be examined. It is apparent that if the series is truncated at the nth term $2n - 2$ derivatives of f_0 are required. Therefore, f_0 must be such that these derivatives can be obtained in analytic form because it is generally impossible to obtain high-order derivatives numerically with accuracy. Furthermore, as has been pointed out in reference 2, the simplest way to insure that conditions at infinity upstream and downstream be uniform is to require that all the derivatives of f_0 vanish as $x \rightarrow \pm\infty$, but of course f_0 must not itself vanish at $x = \pm\infty$.

Thus it is seen that the class of functions that can be used to describe the axial velocity is severely limited.

In reference 1 this velocity distribution is prescribed by the function

$$u_{r=0}(x) = f_0(x) = 0.55 + \frac{0.9}{\sqrt{2\pi}} \int_0^x e^{-\frac{x^2}{2}} dx \tag{2}$$

The following analysis generalizes the procedure of reference 1 so that a much larger variety of design velocity distributions is permitted and in such a way that the series can be carried out to an arbitrary number of terms without any penalty except a trivial increase in machine computing time.

The basic preliminary form of the design velocity function is chosen to be

$$f_p(x) = A + \frac{2cB}{\sqrt{\pi}} \int_0^x e^{-c^2x^2} dx \tag{3}$$

which is only a slight generalization of equation (2). The derivatives of this expression can be obtained by recursion, following a development similar to that of reference 1: Let

$$\Phi(x) = \frac{c}{\sqrt{\pi}} e^{-c^2x^2}$$

then the $m + 1$ derivative of f_p is

$$f_p^{(m+1)}(x) = 2B\,\Phi^{(m)}(x)$$

Substitute

$$\left.\begin{aligned} x &= \frac{z}{c} \\ z^2 &= c^2x^2 \end{aligned}\right\} \tag{4}$$

then

$$\Phi^{(m)}(x) = \frac{c}{\sqrt{\pi}} c^m \frac{d^m}{dz^m} e^{-z^2} = \frac{c^{m+1}}{\sqrt{\pi}}(-1)^m e^{-z^2} H_m(z)$$

or

$$\Phi^{(m)}(x) = (-1)^m c^m \, \Phi(x) \, H_m(z) \tag{5}$$

where $H_m(z)$ is the mth Hermite polynomial (see eq. (29) on p. 91 of ref. 6). The recurrence formula for Hermite polynomials is

$$H_m(z) = 2z \, H_{m-1}(z) - 2(m - 1) \, H_{m-2}(z)$$

Multiply both sides by $(-1)^m c^m \, \Phi(x)$ and then equation (5) becomes

$$\begin{aligned}
\Phi^{(m)}(x) &= 2z(-1)^m c^m \, H_{m-1}(z) - 2(m - 1)(-1)^m c^m \, H_{m-2}(z) \\
&= -2c^2\left[(-1)^{m-1} \frac{z}{c} c^{m-1} \, H_{m-1}(z) + (m - 1)(-1)^{m-2} c^{m-2} \, H_{m-2}(z)\right] \\
&= -2c^2\left[x \, \Phi^{(m-1)}(x) + (m - 1) \, \Phi^{(m-2)}(x)\right]
\end{aligned}$$

which is the desired recurrence formula for the derivatives.

Now consider a more general design velocity function $f_g(x)$, obtained by adding terms to $f_p(x)$. Since the initial and final velocities are determined by the coefficients in $f_p(x)$, these additional terms and all their derivatives must vanish at $\pm\infty$. They should also be such that an arbitrary number of differentiations can be performed analytically in a simple manner. These conditions are satisfied by the form:

$$f_g(x) = f_p(x) + \sum_0^k d_n e^{-x^2} \, H_n(x) \tag{6}$$

The factor e^{-x^2} in each term of the series assures that the conditions at $\pm\infty$ will not be affected. The derivatives of these terms are obtained by the recurrence formula:

$$\frac{d}{dx}\left[e^{-x^2} \, H_n(x)\right] = -e^{-x^2} \, H_{n+1}(x)$$

(ref. 7, p. 786, where the stated formula contains an extraneous factor of 2).

The coefficients d_n can be determined as follows by means of the orthogonality property of the Hermite polynomials. Denoting

$$f_d(x) = f_g(x) - f_p(x)$$

and substituting in equation (6)

$$f_d(x) = \sum_{0}^{k} d_n e^{-x^2} H_n(x) \tag{7}$$

multiplying by $H_m(x)$ and integrating, yields

$$\int_{-\infty}^{\infty} f_d(x)\, H_m(x)\, dx = \sum_{n=0}^{k} d_n \int_{-\infty}^{\infty} e^{-x^2} H_n(x)\, H_m(x)\, dx = \sum_{n=0}^{k} \delta_{mn} 2^n n!\sqrt{\pi}\, d_n$$

Thus

$$d_m = \frac{1}{2^m m!\sqrt{\pi}} \int_{-\infty}^{\infty} f_d(x)\, H_m(x)\, dx$$

where the finiteness of the integral is assured by the nature of $f_d(x)$. Of course the series in equation (7) will, in general, only approximate $f_d(x)$ since only k terms are used.

A simpler, but less accurate, approximation could be obtained by matching the function $f_d(x)$ at k points and obtaining the coefficients as solutions of k simultaneous linear equations.

Actually, neither of these methods for determining the coefficients has been used so far. Rather, the calculation of $f_g(x)$ was programed for visual display, and various values of the coefficients were tried until a close approximation to the desired $f_g(x)$ was obtained.

A description and listing of the computer program is given in the appendix.

DESIGN PROCEDURE

The basic considerations that govern the design of a contraction cone from a prescribed axial velocity distribution have been discussed in reference 2. In general the same considerations are applicable to the design of other kinds of ducts.

After selecting an appropriate axial velocity function the next step in the procedure is to determine several streamlines by solving the equation for the stream function,

$$\psi = \sum_{1}^{k} \frac{(-1)^{n-1} f_g^{(2n-2)}(x)\, r^{2n}}{2^{2n-1} n\left[(n-1)!\right]^2}$$

where

$$f_g(x) = A + \frac{2cB}{\sqrt{\pi}} \int_0^x e^{-c^2x^2} dx + \sum_{n=0}^{k} d_n e^{-x^2} H_n(x) \tag{8}$$

for r at the designated x-stations with fixed values of ψ. A computer program library routine, utilizing interval-halving, was used for this purpose. It may be noted that, in accordance with Descarte's rule of signs, there may be as many as k positive solutions of equation (1) for r^2 and so for r (for fixed ψ and x). However, any possible ambiguity in the solution can be avoided by making an initial estimate of the radius from the one-dimensional approximate relation between velocity and area ratio, after one point on the streamline has been computed.

As successive streamlines are determined, the velocity distributions along the streamlines are also computed. These display a greater radial variation in regions of larger curvature, eventually leading to an adverse velocity gradient in regions of inward turning of the wall. Of course some radial velocity gradient is normally acceptable, and generally a slight adverse velocity gradient can be tolerated by the boundary layer. These factors must be considered when selecting a streamline for the actual duct contour inasmuch as the duct length is shortened by taking larger values of the stream function. Since a short duct implies savings in material, space, and wall-friction losses, the usual design goal is to have the shortest possible duct compatible with acceptable flow quality.

DISCUSSION AND EXAMPLES

The form of the design velocity distribution is determined by the choice of the various parameters in equation (8) in a manner which can be readily demonstrated. Using the identity $\int_0^\infty e^{-c^2x^2} dx = \frac{\sqrt{\pi}}{2c}$, one readily computes that upstream, at $x = -\infty$,

$$f_{g,i} = A - B$$

and downstream, at $x = +\infty$,

$$f_{g,f} = A + B$$

Consequently $A = \frac{1}{2}\left(f_{g,i} + f_{g,f}\right)$, the average of the initial and final velocities, and $B = \frac{1}{2}\left(f_{g,f} - f_{g,i}\right)$. When $d_n = 0$ for all n the velocity is A at $x = 0$; and, inasmuch as the odd-order Hermite polynomials are odd functions of x, the presence of the terms containing these polynomials does not change the velocity at the origin. The even-order polynomials, on the other hand, influence the velocity function in a symmetric (even) manner and, consequently, affect the velocity at the origin.

The nature of the exponential factor $e^{-c^2x^2}$ in the integral term of $f_g(x)$ and $f_p(x)$ assures that $f_p(x)$ will be essentially flat outside of some neighborhood of $x = 0$. Inasmuch as the terms of the summation each contain a factor of e^{-x^2}, the neighborhood of $x = 0$ over which these terms alter $f_p(x)$ depends on the magnitude of c compared to 1.

An example is shown in figure 1. Here an axial velocity distribution obtained by using only the two terms of $f_p(x)$ (eq. (3)) is compared with one obtained with the same values for the parameters except with $d_1 = 0.1$. Thus, the initial and final velocities and the velocity at the origin are all unchanged, but the variation of velocity throughout the design region is radically changed. This distribution $\left(\text{with } d_1 = 0.1\right)$ has appropriate characteristics for a contraction-cone design, that is, it is relatively short between the flat ends with smoothly varying curvature. Figure 2 shows a contraction cone designed from this velocity distribution together with several internal streamlines. Figure 3 shows the distributions of velocity along these streamlines. As expected the radial variation of velocity is greatest near the entrance where the curvature is greatest.

A different kind of design velocity distribution is shown in figure 4. Here the initial and final velocities were prescribed to be 0.5 and 1.0, respectively, with the terms with Hermite polynomials all chosen to have zero coefficients except $d_0 = 0.6$. Thus the maximum velocity occurs at $x = 0$, where $f_g = A + d_0 = 1.35$. Such a velocity distribution (one with the peak velocity between the ends) cannot be described with the original Tsien formulation.

A duct designed from this velocity distribution is shown in figure 5 together with some streamlines, and the wall velocity distribution is shown in figure 4. The radial variation of velocity is noticeable at the minimum, where the curvature is relatively large. This result may be compared with that of figure 3 for the contraction cone where the relatively small curvature at the minimum results in a nearly uniform flow there.

CONCLUDING REMARKS

A method for generalizing the Tsien procedure of contraction-cone design has been presented. The class of design velocity distributions is enlarged in such a way that conditions far upstream and downstream are unchanged, and so that the derivatives required in the calculation can be obtained by a recurrence formula rather than by numerical differentiation. The generalized method is no longer restricted to contraction cones but now permits the design of diffusers and converging-diverging ducts.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., September 26, 1972.

APPENDIX

COMPUTER PROGRAM FOR LOW-SPEED DUCT DESIGN

A computer program has been developed which will calculate the wall contour for a subsonic duct. The program is written in the FORTRAN IV language for use on CDC 6000 series computers. Since it was desired to take an interactive approach to the problem, the program has been implemented on the LRC interactive graphics system using the CDC 250 Cathode Ray Tube (CRT). The program listing and a description of its input and output are presented in this appendix.

Description of Program

The program is basically divided into two parts. Part I of the program builds an $I \times 4$ design table where the stream function ψ, the axial coordinate x, the radial coordinate r, and the number of derivative terms N are column vectors; I is the number of row entries. The program computes the value of the stream function at any point x,r or the value of r for an arbitrary value of ψ at some specified axial coordinate. By employing these two computations (each of which stores an entry in the design table), the user can determine the neighborhood of the desired solution and approximate the boundaries of its convergence.

Part II of the program computes the radial coordinates which agree with some specified range of the axial coordinates and a fixed value of the stream function (streamlines). In addition, it gives the corresponding velocity distribution in the duct and its axial and radial components. The streamlines are visually displayed on the CRT with a visual cue at the point where the velocity is no longer monotonically increasing. The plotting specifications are variable and may be input during program execution.

Subprogram Index

The following is an index of the subprograms called by this program and their sources. AUTHOR denotes routines written by the authors of this paper. CALCOMP indicates routines available as a part of the CalComp graphic output system. CRT indicates routines which are a part of the LRC interactive graphic system. LIBRARY denotes routines which are on the LRC computer complex system tape. The functions of the authors' routines are also given.

Subprogram	Source	Function
ABS	LIBRARY	
AXES	CALCOMP	
CALPLT	CALCOMP	
CDC250	CRT	
DAYTIM	LIBRARY	
DERIV	AUTHOR	Computes the derivatives of $f_g(x)$, equation (6)
ENCODE	LIBRARY	
EXP	LIBRARY	
FACT	AUTHOR	Computes the factorial of an integer
FLOAT	LIBRARY	
FOFR	AUTHOR	Evaluates $\psi - f_g(x)$ for routine ITR2
FUNC	AUTHOR	Evaluates the integral in $f_g(x)$
IFIX	LIBRARY	
ITR2	LIBRARY	
LEROY	CALCOMP	
LINPLT	CALCOMP	
MESAGE	CRT	
MGAUSS	LIBRARY	
NEXT	CRT	

Subprogram	Source	Function
NOTATE	CALCOMP	
PARAMS	CRT	
PNTPLT	CALCOMP	
RECIN	LIBRARY	
RECOUT	LIBRARY	
RVALUE	AUTHOR	Computes r, velocities u and v, and G for ψ at x
SCREEN	CRT	
SIGN	LIBRARY	
SQRT	LIBRARY	
STREAM	AUTHOR	Computes ψ at any point x,r

Program Input

The first two cards should contain the velocity distribution function (free field). It will be printed as a part of the header on the first page of program output.

The next input block should contain the velocity distribution function parameters and the parameters used in the iterative method to determine the radius of the duct. These variables should be input under the FORTRAN IV Namelist format. A description of these variables and the corresponding names used by the source program are as follows:

Name	Symbol	Description
$FPARAM		Name required by input routine
AG1		Lower bound on the neighborhood of r
AG2		Upper bound on the neighborhood of r
C2	c^2	Velocity distribution function parameter

Name	Symbol	Description
DELR		Initial size of the scanning interval $r_{i+1} = r_i + \mathrm{DELR}$ If $r_i < r < r_{i+1}$, $\mathrm{DELR} = \mathrm{DELR}/2$
D1	d_1	Velocity distribution function parameter (see eq. (6))
D2	d_2	Velocity distribution function parameter (see eq. (6))
EPS1	Σ_1	Relative error criterion for determining convergence. If $\lvert r_i \rvert > \Sigma_1$, $\left\lvert \frac{r_i - r_{i-1}}{r_1} \right\rvert \leqq \Sigma_1$ implies convergence
EPS2	Σ_2	Absolute error criterion for determining convergence. If $r_i \leqq \Sigma_1$, $\lvert r_i - r_{i-1} \rvert \leqq \Sigma_2$ implies convergence
MAXIT		Maximum number of iterations to be used
NACC	N	Number of derivative terms to be used
V1	$f_{g,i}$	Desired initial velocity in the duct
V2	$f_{g,f}$	Desired final velocity in the duct
$		Required by input routine

The next input section forms the basis for the design table. Each card should contain an axial coordinate (columns 11-20, F10.4) and a radial coordinate (columns 21-30, F10.4). These coordinates should be chosen such that the stream function is specified throughout the entire field of interest. The value of the stream function is computed at these points and stored in the design table ordered on decreasing values of ψ.

The final input block is to be input at the CRT station. The variables in this block may be changed at any time during execution of the program affording interactive control over the program. By varying these parameters the user may take advantage of program options to (1) add and delete entries in the design table, (2) make limited changes to the velocity distribution function, and (3) vary the iteration scheme to achieve convergence.

Name	Symbol	Description
AG1		*
AG2		*
A1	A	Velocity distribution function parameter (see eq. (3))
A2	$2\sqrt{2}\,cB$	Velocity distribution function parameter
C2		*
DELR		*
DPSI		Increment from PSIMIN to PSIMAX
DX		Increment from XMIN to XMAX
D1		*
D2		*
EPS1		*
EPS2		*
GDIST		Length of Y-axis for velocity plot (in.)
GDV		Y-axis scale for velocity plot (units/in.)
GMAX		Maximum velocity computed
GMIN		Minimum velocity computed
GOR		Y-axis origin for velocity plot
I		Row number in design table

Name	Symbol	Description
IP1		Printing control for part I of program
IP2		Printing control for part II of program
MAXIT		*
NACC		*
PSI	ψ	*
PSIMAX		Maximum streamline to be computed
PSIMIN		Minimum streamline to be computed
R	r	*
RDIST		Length of Y-axis for radial plot (in.)
RDV		Y-axis scale for radial plot (units/in.)
RMAX		Maximum radius computed
RMIN		Minimum radius computed
ROR		Y-axis origin for radial plot
V1		*
V2		*
X	x	*
XDIST		Length of X-axis (in.)
XDV		X-axis scale (units/ in.)
XMAX		Maximum value of x for which ψ is computed

Name	Symbol	Description
XMIN		Minimum value of x for which ψ is computed
XOR		X-axis origin

NOTE:

The starred (*) variables are defined previously in the appendix.

A sample input follows:

```
F(X) = A1 + A2*I(SQRT(2PI)*E**(-C**2*X**2))DX + E** - (X**2)*(D1*H0 + D2*H1)
I = INTEGRAL FROM 0 TO X
$FPARAM AG1 = 0.0, AG2 = 1.0, C2 = 1.0, DELR = 0.1, D1 = 0.0, D2 = 0.1, EPS1 = 1.E - 6,
EPS2 = 1.E - 6, MAXIT = 200, NACC = 10, V1 = 0.133, V2 = 1.0$
     1.0      1.1
     1.0       .9
     0.0      1.0
    -1.0       .9
    -1.0      0.0
     1.0       .7
     1.0       .6
     1.0       .4
    -1.0       .7
    -1.0       .6
```

Program Output

On the first page of printed output, the velocity distribution function, its parameters, and the design table are printed.

On the following pages, the radial distribution is shown for ψ = PSIMIN to ψ = PSIMAX incremented by DPSI over an axial range of X = XMIN to X = XMAX incremented by DX. The resultant velocity G and its axial u and radial v components are also included.

The plotted output included the radial distribution curves, the velocity distribution curves, and the centerline velocity curve. They are displayed on the CRT during program execution with the capability of saving them for post-processing on the Calcomp plotter. The plot format is similar to that of the figures shown in the main body of the paper.

Following is the printed output which corresponds to the input previously presented. Streamlines are shown for ψ = 0.003, 0.006, 0.009, 0.012, and 0.013. The centerline velocity distribution is shown at $\psi = 0.0$. The proposed wall contour is streamline $\psi = 0.013$. Finally, the source program listing is presented.

```
                              CONTRACTION CONE DESIGN TABLE                 DATE      04/18/72

VELOCITY DISTRIBUTION FUNCTION   F(X)=A1+A2*I(SQRT(2PI))*E**-(C**2*X**2)DX + E**-X**2*(D1*HO + D2*H1 )
                                    I =  INTEGRAL   FROM  0 TO X

      INIT. VEL.=    .1330       FINAL VEL.=   1.0000    A1=    .5665     A2=   1.2261     C**2= 1.00
                                          D1=  0.0000D2=   .1000
```

I	PSI	X	R	N
1	.65341	1.00000	1.10000	10
2	.42800	1.00000	.90000	10
3	.28325	0.00000	1.00000	10
4	.25399	1.00000	.70000	10
5	.18511	1.00000	.60000	10
6	.08125	1.00000	.40000	10
7	.05000	-1.20000	-999.00000	10
8	.04000	-1.20000	.94307	10
9	.03592	-4.00000	.73491	10
10	.03206	-1.00000	1.10000	10
11	.03087	-1.00000	.90000	10
12	.03000	-1.20000	.79327	10
13	.02700	4.00000	.23238	10
14	.02359	-1.00000	.70000	10
15	.02016	1.00000	.20000	10
16	.01883	-1.00000	.60000	10
17	.01300	1.20000	.15974	20
18	.01300	1.20000	.15974	15
19	.01300	1.20000	.15974	13
20	.01300	1.20000	.15974	11
21	.01300	1.20000	.15974	10
22	.01300	-1.20000	.49403	20
23	.01300	-1.20000	.49403	15
24	.01300	-1.20000	.49403	10
25	.00939	-1.00000	.40000	10
26	.00503	1.00000	.10000	10
27	.00250	-1.00000	.20000	10
28	.00063	-1.00000	.10000	10
29	0.00000	0.00000	0.00000	10
30	0.00000	1.00000	0.00000	10
31	0.00000	-1.00000	0.00000	10

R AND G DISTRIBUTION FOR CURVE 1 DATE 0

PSI = 0.000000 TO 0.000000 X= -1.200000 TO 1.200000

0.000000

INIT. VEL.= .1330 FINAL VEL.= 1.0000 A1= .5665 A2= 1.2261 C**2= 1.0000 N= 10
D1= 0.0000 C2= .1000 PLOT NO. 2

PT	X	R	U	V	G
1	-1.200000	0.000000	.115016	0.000000	.115016
2	-1.120000	0.000000	.118182	0.000000	.118182
3	-1.040000	0.000000	.123752	0.000000	.123752
4	-.960000	0.000000	.132286	0.000000	.132286
5	-.880000	0.000000	.144339	0.000000	.144339
6	-.800000	0.000000	.160432	0.000000	.160432
7	-.720000	0.000000	.181016	0.000000	.181016
8	-.640000	0.000000	.206426	0.000000	.206426
9	-.560000	0.000000	.236854	0.000000	.236854
10	-.480000	0.000000	.272313	0.000000	.272313
11	-.400000	0.000000	.312620	0.000000	.312620
12	-.320000	0.000000	.357383	0.000000	.357383
13	-.240000	0.000000	.406006	0.000000	.406006
14	-.160000	0.000000	.457707	0.000000	.457707
15	-.080000	0.000000	.511553	0.000000	.511553
16	.000000	0.000000	.566500	0.000000	.566500
17	.080000	0.000000	.621447	0.000000	.621447
18	.160000	0.000000	.675293	0.000000	.675293
19	.240000	0.000000	.726994	0.000000	.726994
20	.320000	0.000000	.775617	0.000000	.775617
21	.400000	0.000000	.820380	0.000000	.820380
22	.480000	0.000000	.860687	0.000000	.860687
23	.560000	0.000000	.896146	0.000000	.896146
24	.640000	0.000000	.926574	0.000000	.926574
25	.720000	0.000000	.951984	0.000000	.951984
26	.800000	0.000000	.972568	0.000000	.972568
27	.880000	0.000000	.988661	0.000000	.988661
28	.960000	0.000000	1.000714	0.000000	1.000714
29	1.040000	0.000000	1.009248	0.000000	1.009248
30	1.120000	0.000000	1.014818	0.000000	1.014818
31	1.200000	0.000000	1.017984	0.000000	1.017984

R AND G DISTRIBUTION FOR CURVE 1 DATE C

PSI = .003000 TO .C12000 X= -1.200000 TO 1.200000

.003000

INIT. VEL.= .1330 FINAL VEL.= 1.0000 A1= .5665 A2= 1.2261 C**2= 1.0000 N= 10

D1= 0.0000 D2= .1000 PLOT NO. 1

PT	X	R	U	V	G
1	-1.200000	.230328	.111200	-.002312	.111224
2	-1.120000	.227665	.113348	-.005277	.113471
3	-1.040000	.222792	.118007	-.008911	.118343
4	-.960000	.215600	.125861	-.013064	.126537
5	-.880000	.206315	.137559	-.017500	.138668
6	-.800000	.195456	.153657	-.021945	.155216
7	-.720000	.183698	.174572	-.026139	.176518
8	-.640000	.171706	.200570	-.029872	.202783
9	-.560000	.160021	.231754	-.033001	.234091
10	-.480000	.149019	.268053	-.035444	.270387
11	-.400000	.138915	.309219	-.037164	.311445
12	-.320000	.129804	.354812	-.038161	.356858
13	-.240000	.121700	.404204	-.038456	.406029
14	-.160000	.114563	.456596	-.038091	.458182
15	-.080000	.108327	.511043	-.037120	.512390
16	.000000	.102914	.566500	-.035611	.567618
17	.080000	.098243	.621866	-.033637	.622775
18	.160000	.094234	.676043	-.031282	.676767
19	.240000	.090816	.727994	-.028633	.728557
20	.320000	.087920	.776791	-.025779	.777219
21	.400000	.085487	.821661	-.022808	.821977
22	.480000	.083461	.862014	-.019807	.862242
23	.560000	.081795	.897469	-.016854	.897627
24	.640000	.080443	.927849	-.014021	.927955
25	.720000	.079364	.953177	-.011368	.953245
26	.800000	.078523	.973653	-.008943	.973694
27	.880000	.077884	.989621	-.006782	.989645
28	.960000	.077416	1.001540	-.004905	1.001552
29	1.040000	.077091	1.009936	-.003321	1.009941
30	1.120000	.076882	1.015372	-.002024	1.015374
31	1.200000	.076764	1.018413	-.001001	1.018413

R AND G DISTRIBUTION FOR CURVE 2 DATE 0

PSI = .003000 TO .012000 X= -1.200000 TO 1.200000

.006000

INIT. VEL.= .1330 FINAL VEL.= 1.0000 A1= .5665 A2= 1.2261 C**2= 1.0000 N= 10
D1= 0.0000 D2= .1000 PLOT NO. 1

PT	X	R	U	V	G
1	-1.200000	.328570	.107372	-.002126	.107393
2	-1.120000	.325511	.108370	-.006303	.108554
3	-1.040000	.319084	.111974	-.011549	.112568
4	-.960000	.309003	.119031	-.017647	.120332
5	-.880000	.295567	.130318	-.024217	.132549
6	-.800000	.279622	.146432	-.030806	.149637
7	-.720000	.262294	.167741	-.036990	.171771
8	-.640000	.244668	.194411	-.042452	.198992
9	-.560000	.227588	.226432	-.046988	.231256
10	-.480000	.211602	.263642	-.050496	.268434
11	-.400000	.197005	.305720	-.052940	.310270
12	-.320000	.183908	.352180	-.054334	.356347
13	-.240000	.172304	.402367	-.054721	.406071
14	-.160000	.162116	.455467	-.054166	.458676
15	-.080000	.153236	.510527	-.052751	.513245
16	.000000	.145543	.566500	-.050573	.568753
17	.080000	.138913	.622288	-.047742	.624117
18	.160000	.133230	.676800	-.044373	.678253
19	.240000	.128389	.729001	-.040592	.730131
20	.320000	.124291	.777973	-.036525	.778830
21	.400000	.120849	.822948	-.032297	.823582
22	.480000	.117987	.863348	-.028029	.863803
23	.560000	.115633	.898797	-.023833	.899113
24	.640000	.113724	.929128	-.019811	.929339
25	.720000	.112203	.954373	-.016048	.954508
26	.800000	.111017	.974740	-.012610	.974821
27	.880000	.110117	.990582	-.009548	.990628
28	.960000	.109460	1.002365	-.006891	1.002389
29	1.040000	.109004	1.010623	-.004650	1.010634
30	1.120000	.108712	1.015925	-.002819	1.015929
31	1.200000	.108550	1.018841	-.001375	1.018842

R AND G DISTRIBUTION FOR CURVE 3 DATE 0

PSI = .003000 TO .012000 X= -1.200000 TO 1.200000

.009000

INIT. VEL.= .1330 FINAL VEL.= 1.0000 A1= .5665 A2= 1.2261 C**2= 1.0000 N= 10
D1= 0.0000 D2= .1000 PLOT NO. 1

PT	X	R	U	V	G
1	-1.200000	.406027	.103549	-.001090	.103555
2	-1.120000	.403321	.103244	-.006144	.103427
3	-1.040000	.396189	.105612	-.012686	.106372
4	-.960000	.384037	.111722	-.020452	.113579
5	-.880000	.367172	.122528	-.028909	.125892
6	-.800000	.346805	.138678	-.037398	.143632
7	-.720000	.324588	.160464	-.045322	.166741
8	-.640000	.302072	.187910	-.052254	.195040
9	-.560000	.280397	.220867	-.057952	.228344
10	-.480000	.260254	.259067	-.062313	.266455
11	-.400000	.241977	.302116	-.065319	.309096
12	-.320000	.225664	.349485	-.067005	.355850
13	-.240000	.211270	.400495	-.067438	.406133
14	-.160000	.198675	.454320	-.066708	.459191
15	-.080000	.187723	.510004	-.064921	.514119
16	.000000	.178253	.566500	-.062201	.569905
17	.080000	.170104	.622715	-.058682	.625474
18	.160000	.163128	.677562	-.054510	.679751
19	.240000	.157189	.730015	-.049837	.731714
20	.320000	.152166	.779161	-.044817	.780449
21	.400000	.147952	.824242	-.039605	.825193
22	.480000	.144448	.864687	-.034350	.865369
23	.560000	.141568	.900129	-.029188	.900602
24	.640000	.139235	.930411	-.024243	.930727
25	.720000	.137377	.955572	-.019619	.955773
26	.800000	.135929	.975829	-.015398	.975950
27	.880000	.134833	.991545	-.011641	.991613
28	.960000	.134033	1.003191	-.008384	1.003226
29	1.040000	.133480	1.011310	-.005639	1.011326
30	1.120000	.133127	1.016477	-.003398	1.016483
31	1.200000	.132932	1.019267	-.001634	1.019268

R AND G DISTRIBUTION FOR CURVE 4 DATE 0

PSI = .003000 TO .012000 X= -1.200000 TO 1.200000

.012000

INIT. VEL.= .1330 FINAL VEL.= 1.0000 A1= .5665 A2= 1.2261 C**2= 1.0000 N= 10
D1= 0.0000 D2= .1000 PLOT NO. 1

PT	X	R	U	V	G
1	-1.200000	.473172	.059754	.000634	.099756
2	-1.120000	.471501	.057968	-.005067	.098099
3	-1.040000	.464383	.098875	-.012724	.099690
4	-.960000	.450723	.103838	-.022057	.106155
5	-.880000	.430732	.114070	-.032366	.118573
6	-.800000	.406059	.130289	-.042732	.137118
7	-.720000	.379047	.152666	-.052337	.161388
8	-.640000	.351812	.181023	-.060650	.190912
9	-.560000	.325807	.215036	-.067404	.225353
10	-.480000	.301837	.254317	-.072514	.264453
11	-.400000	.280242	.298402	-.075995	.307927
12	-.320000	.261075	.346724	-.077912	.355370
13	-.240000	.244238	.398586	-.078362	.406216
14	-.160000	.229554	.453154	-.077458	.459727
15	-.080000	.216820	.509473	-.075332	.515013
16	.000000	.205829	.566500	-.072128	.571073
17	.080000	.196385	.623146	-.068006	.626845
18	.160000	.188311	.678330	-.063133	.681262
19	.240000	.181443	.731035	-.057687	.733308
20	.320000	.175640	.780356	-.051847	.782076
21	.400000	.170773	.825542	-.045790	.826811
22	.480000	.166729	.866032	-.039689	.866941
23	.560000	.163409	.901467	-.033701	.902097
24	.640000	.160719	.931698	-.027969	.932117
25	.720000	.158579	.956774	-.022612	.957041
26	.800000	.156914	.976920	-.017727	.977081
27	.880000	.155654	.992508	-.013381	.992598
28	.960000	.154736	1.004017	-.009616	1.004063
29	1.040000	.154103	1.011997	-.006446	1.012017
30	1.120000	.153700	1.017029	-.003862	1.017036
31	1.200000	.153480	1.019692	-.001829	1.019693

R AND G DISTRIBUTION FOR CURVE 1 DATE 0

PSI = .013000 TO .013000 X= -1.200000 TO 1.200000

.013000

INIT. VEL.= .1330 FINAL VEL.= 1.0000 A1= .5665 A2= 1.2261 C**2= 1.0000 N= 10
D1= 0.0000 D2= .1000 PLOT NO. 3

PT	X	R	U	V	G
1	-1.200000	.494033	.098499	.001352	.098509
2	-1.120000	.492865	.096175	-.004516	.096281
3	-1.040000	.485923	.096534	-.012509	.097342
4	-.960000	.471882	.101060	-.022356	.103503
5	-.880000	.450883	.111075	-.033294	.115958
6	-.800000	.424748	.127329	-.044300	.134815
7	-.720000	.396100	.149935	-.054472	.159523
8	-.640000	.367278	.178632	-.063237	.189495
9	-.560000	.339845	.213028	-.070329	.224338
10	-.480000	.314635	.252692	-.075674	.263780
11	-.400000	.291979	.297139	-.079299	.307538
12	-.320000	.271913	.345789	-.081284	.355214
13	-.240000	.254311	.397942	-.081734	.406249
14	-.160000	.238978	.452762	-.080771	.459910
15	-.080000	.225693	.509295	-.078536	.515315
16	.000000	.214233	.566500	-.075180	.571467
17	.080000	.204392	.623290	-.070368	.627306
18	.160000	.195981	.678587	-.065777	.681768
19	.240000	.188830	.731377	-.060091	.733841
20	.320000	.182788	.780756	-.053997	.782621
21	.400000	.177723	.825977	-.047680	.827352
22	.480000	.173515	.866482	-.041318	.867466
23	.560000	.170060	.901914	-.035076	.902596
24	.640000	.167263	.932128	-.029102	.932582
25	.720000	.165037	.957175	-.023521	.957464
26	.800000	.163306	.977284	-.018432	.977458
27	.880000	.161997	.992829	-.013906	.992927
28	.960000	.161044	1.004292	-.009986	1.004342
29	1.040000	.160386	1.012225	-.006687	1.012247
30	1.120000	.159969	1.017212	-.003998	1.017220
31	1.200000	.159742	1.019833	-.001884	1.019835

```
      PROGRAM CNCONF(INPUT=1001,OUTPUT=1001,TAPE5=INPUT,TAPE6=OUTPUT,TAP
     1E8)
C
C               LOW  SPEED DUCT DESIGN
C
      DIMENSION PSIA(100), A(100), RA(100), MESG(10), TONE(8), XPLOT(500
     1), YPLOT(500), NAC(100)
      DIMENSION ORG(2), DV(2), DIST(2), JRCD(2)
      DIMENSION DATE(2), FCT(8,2)
      EQUIVALENCE (ROR,ORG(1)), (GOR,ORG(2)), (RDV,DV(1)), (GDV,DV(2)),
     1(RDIST,DIST(1)), (GDIST,DIST(2))
      COMMON /YD1/ DELR,EPS1,EPS2,MAXIT
      COMMON /YD2/ NACC,PSI,X,R,U,V,G
      COMMON /YD3/ A1,A2,C2,D1,D2
      COMMON /YD4/ AG1,AG2
      NAMELIST/FPARAM/ AG1, AG2, C2, DELR, D1, D2, EPS1, EPS2,
     1  MAXIT, NACC, V1, V2
C
C                    PROGRAM          INITIALIZATION
      CALL CDC250
      CALL LEROY
      CALL SCREEN (1.0,1.0,0.8)
      S2=SQRT(2.0)
      MNA=100
      MPT=500
      IP1=IP2=0
      JNK1=0$JNK2=-1
      LPLT=0
      CALL DAYTIM (DATE)
      READ 110, FCT
110   FORMAT (8A10)
      READ(5,FPARAM)
C
      CALL PARAMS
      CALL PARAMS (3LPSI,PSI)
      CALL PARAMS (1LX,X,1LR,R,1LI,I)
      CALL PARAMS (4LDELR,DELR,5LMAXIT,MAXIT)
      CALL PARAMS (4LEPS1,EPS1,4LEPS2,EPS2)
      CALL PARAMS (2LA1,A1,2LA2,A2)
      CALL PARAMS (4LNACC,NACC)
      CALL PARAMS (3LAG1,AG1,3LAG2,AG2)
      CALL PARAMS (3LIP1,IP1,3LIP2,IP2)
      CALL PARAMS (2LV1,V1,2LV2,V2,2LC2,C2)
      CALL PARAMS (2LD1,D1,2LD2,D2)
      CALL MESAGE (1,36H INSERT  INITIAL VALUES FOR PSI EDIT,36)
      CALL MESAGE (1,25H ANY FN KEY WILL CONTINUE,25)
      CALL NEXT (KEY)
      J3=1
      GO TO 510
120   CONTINUE
C
```

```
C                          PART   I
C        GENERATE  INITIAL  PSI  DISTRIBUTION  TABLE
      NA=0
130   READ 140, X,R
      IF(EOF,5) 180, 150
140   FORMAT (10X,2F10.4)
150   NA=NA+1
      IF (NA.LE.MNA) GO TO 170
      PRINT 160, MNA,NA
160   FORMAT (39H0MAXIMUM INITIAL PSI DIMENSION EXCEEDED,2I10)
      GO TO 130
C                         COMPUTE       PSI
170   CALL STREAM
      PSIA(NA)=PSI$A(NA)=X$RA(NA)=R
      NAC(NA)=NACC
      GO TO 130
180   IF (NA.GT.MNA) NA=MNA
      J1=27
      ENCODE (J1,190,MESG) NA
190   FORMAT (1X,I5,21H INITIAL PSI COMPUTED)
      CALL MESAGE (1,MESG, J1)
C
C
C        ORDER    INITIAL      PSI    TABLE     (  DESCENDING     )
      J3=NA-1
      DO 210 J1=1,J3
      J2=J1+1$J5=J1
      DO 200 J4=J2,NA
      IF (PSIA(J5).LT.PSIA(J4)) J5=J4
200   CONTINUE
      IF (J5.EQ.J1) GO TO 210
      SAV=PSIA(J1)$PSIA(J1)=PSIA(J5)$PSIA(J5)=SAV
      SAV=A(J1)$A(J1)=A(J5)$A(J5)=SAV
      SAV=RA(J1)$RA(J1)=RA(J5)$RA(J5)=SAV
      SAV=NAC(J1)$NAC(J1)=NAC(J5)$NAC(J5)=SAV
210   CONTINUE
C
C        DISPLAY  INITIAL      PSI    TABLE
220   JRT=1
230   J2=20
      J5=50
      DO 260 J1=1,NA,J2
      J3=J1+J2-1
      IF (J3.GT.NA) J3=NA
      DO 250 J4=J1,J3
      ENCODE (J5,240,MESG) J4,PSIA(J4),A(J4),RA(J4),NAC(J4)
240   FORMAT (3H I=,I2,5H PSI=,F13.6,3H X=,F8.4,3H R=,F8.4,3H N=,I2)
      CALL MESAGE (1,MESG, J5)
250   CONTINUE
      CALL MESAGE (3,33H ANY FN KEY WILL CONTINUE DISPLAY,33)
      CALL NEXT (KEY)
260   CONTINUE
C
```

```
C         EDIT       INITIAL       PSI    TABLE
C
      CALL MESAGE (1,25H END OF PSI RANGE DISPLAY,25)
      GO TO (270,620), JRT
270   CALL MESAGE (1,24H BEGIN EDIT RANGE OF PSI,24)
      CALL MESAGE (1,27H VARIABLES ARE  X,   R,   I,27)
280   CALL MESAGE (1,37H FN KEY 1 WILL COMPUTE PSI AT X AND R,37)
      CALL MESAGE (1,36H FN KEY 2 WILL INSERT PSI, X, AND  R,36)
      CALL MESAGE (1,23H FN KEY 3 WILL DELETE I,23)
      CALL MESAGE (1,39H FN KEY 4 WILL DISPLAY PSI,X,AND R AT I,39)
      CALL MESAGE (1,32H FN KEY 5 WILL DISPLAY PSI RANGE,32)
      CALL MESAGE (1,36H FN KEY 6 WILL END EDIT AND CONTINUE,36)
      CALL MESAGE (1,37H FN KEY 7 WILL COMPUTE R AT PSI AND X,37)
      CALL MESAGE (1,41H FN KEY 8 SIMPLE TRANSFER TO PLOT ROUTINE,41)
      CALL MESAGE (1,38H FN KEY 9  WILL  DELETE  ENTIRE  TABLE,38)
      CALL MESAGE (1,33H FN KEY 10 WILL  COMPUTE  A1,  A2,33)
      CALL MESAGE (1,38H ANY OTHER FN KEY WILL DISPLAY OPTIONS,38)
C
      CALL NEXT (KEY)
      IF (KEY.EQ.1) GO TO 290
      IF (KEY.EQ.2) GO TO 310
      IF (KEY.EQ.3) GO TO 400
      IF (KEY.EQ.4) GO TO 430
      IF (KEY.EQ.5) GO TO 220
      IF (KEY.EQ.6) GO TO 540
      IF (KEY.EQ.7) GO TO 440
      IF (KEY.EQ.8) GO TO 620
      IF (KEY.EQ.9) GO TO 490
      IF (KEY.EQ.10) GO TO 500
      GO TO 280
C
C                        COMPUTE        PSI
290   CALL STREAM
      ENCODE (50,300,MESG) PSI,X,R,NACC
300   FORMAT (5H PSI=,F16.6,3H X=,F8.4,3H R=,F8.4,3H N=,I4)
      CALL MESAGE (1,MESG,50)
      GO TO 280
C
C        INSERT    PSI      IN      TABLE
310   IF (NA.EQ.MNA) GO TO 390
      IF (PSI.LT.PSIA(1)) GO TO 320
      J1=1
      GO TO 340
320   DO 330 J1=2,NA
      IF ((PSI.LE.PSIA(J1-1)).AND.(PSI.GE.PSIA(J1))) GO TO 340
330   CONTINUE
      J1=NA+1
      GO TO 360
340   DO 350 J2=J1,NA
```

```
      J3=NA-J2+J1
      PSIA(J3+1)=PSIA(J3)$A(J3+1)=A(J3)$RA(J3+1)=RA(J3)
      NAC(J3+1)=NAC(J3)
350   CONTINUE
360   PSIA(J1)=PSI$A(J1)=X$RA(J1)=R
      NAC(J1)=NACC
      NA=NA+1
370   ENCODE (78,380,MESG) NA,J1,NAC(J1),PSIA(J1),A(J1),RA(J1)
380   FORMAT (9H TOTAL I=,I4,3H I=,I4,3H N=,I3,4X,5H PSI=,F16.6,4H  X=,F
     19.4,4H  R=,F9.4)
      CALL MESAGE (1,MESG,30)
      CALL MESAGE (1,MESG(4),47)
      GO TO 280
390   CALL MESAGE (4,23H MAX I HAS BEEN REACHED,23)
      GO TO 280
C
C       DELETE      ENTRY     I     IN     PSI    TABLE
400   DO 410 J2=I,NA
      PSIA(J2)=PSIA(J2+1)
      A(J2)=A(J2+1)
      RA(J2)=RA(J2+1)
      NAC(J2)=NAC(J2+1)
410   CONTINUE
      NA=NA-1
      ENCODE (30,420,MESG) NA,I
420   FORMAT (9H TOTAL I=,I5,I8,8H DELETED)
      CALL MESAGE (1,MESG,30)
      GO TO 280
C
430   J1=I
      GO TO 370
C
C       COMPUTE    R    FOR    PSI    AT    X
440   CALL RVALUE (ICODE)
      ENCODE (50,450,MESG) PSI,X
450   FORMAT (5H PSI=,F16.8,5H   X=,F16.8)
      CALL MESAGE (1,MESG,42)
      ENCODE (50,460,MESG) R,G
460   FORMAT (3H R=,F16.8,5H   G=,F16.8)
      CALL MESAGE (1,MESG,40)
      ENCODE (50,470,MESG) U,V
470   FORMAT (3H U=,F16.8,6H    V=,F16.8)
      CALL MESAGE (1,MESG,41)
      ENCODE (50,480,MESG) NACC,ICODE
480   FORMAT (3H N=,I2,12H ERROR CODE=,I3)
      CALL MESAGE (1,MESG,20)
      CALL MESAGE (1,25H ANY FN KEY WILL CONTINUE,25)
      CALL NEXT (KEY)
      GO TO 280
490   NA=0$PSIA(1)=PSIA(2)=9.E10
      CALL MESAGE (1,14H TABLE DELETED,14)
      GO TO 280
C
500   J3=2
      GO TO 510
```

```
C
C       COMPUTE     FUNCTION    PARAMETERS     A1       A2
C
510    C2=ABS(C2)
       A1=0.5*(V1+V2)
       A2=S2*SQRT(C2)*(V2-V1)
       ENCODE (100,520,MESG) V1,V2,C2,A1,A2
520    FORMAT (12H INIT. VEL.=,F8.4,12H FINAL VEL.=,F8.4,4H C2=,F10.6,6X,
      14H A1=,F16.8,4H A2=,F16.8)
       CALL MESAGE (1,MESG,40)
       CALL MESAGE (1,MESG(5),20)
       CALL MESAGE (1,MESG(7),40)
       ENCODE (34,530,MESG) D1,D2
530    FORMAT (4H D1=,F13.6,4H D2=,F13.6)
       CALL MESAGE (1,MESG,34)
       GO TO (120,280), J3
C
C
C               END     INITIAL       PSI     EDIT
540    CALL MESAGE (3,28H REPEAT FN KEY 6 TO END EDIT,28)
       CALL MESAGE (1,38H ANY OTHER FN KEY WILL DISPLAY OPTIONS,38)
       CALL NEXT (KEY)
       IF (KEY.NE.6) GO TO 280
       IF (IP1.NE.0) GO TO 610
C
C       OUTPUT    INITIAL        PSI    TABLE
       DO 600 J1=1,NA
       IF( MOD( J1-1. 35 ) .NE. 0  )   GO   TO   595
       PRINT  550,   DATE(1)
  550  FORMAT(1H1//50X, *CONTRACTION CONE DESIGN TABLE*, 15X, *DATE*,
      1  5X, A10)
       PRINT  560,   FCT
560    FORMAT (/10X,30HVELOCITY DISTRIBUTION FUNCTION,5X,8A10/45X,8A10)
       PRINT  570, V1,  V2,   A1,   A2, C2
570    FORMAT (/20X,11HINIT. VEL.=,F9.4,5X,11HFINAL VEL.=,F9.4,5X,3HA1=,F
      19.4,5X,3HA2=,F9.4,5X,5HC**2=,F5.2)
       PRINT 571,D1, D2
  571  FORMAT(53X, *D1=*, F8.4, *     D2=*, F8.4)
       PRINT   580
580    FORMAT (//32X,1HI,17X,3HPSI,19X,1HX,19X,1HR,5X,1HN)
  595  CONTINUE
       PRINT 590, J1,PSIA(J1),A(J1),RA(J1),NAC(J1)
590    FORMAT (28X,I5,3F20.5,I6)
600    CONTINUE
610    CONTINUE
C
C
```

```
C                          PART     II
C       SET-UP             PLOT          PARAMETERS
C
      CALL PARAMS (4LXMIN,XMIN,2LDX,DX,4LXMAX,XMAX)
      CALL PARAMS (6LPSIMIN,PSIMIN,4LDPSI,DPSI,6LPSIMAX,PSIMAX)
      CALL PARAMS (3LROR,ROR,3LRDV,RDV,5LRDIST,RDIST)
      CALL PARAMS (3LGOR,GOR,3LGDV,GDV,5LGDIST,GDIST)
      CALL PARAMS (3LXOR,XOR,3LXDV,XDV,5LXDIST,XDIST)
      CALL PARAMS (4LRMIN,RMIN,4LRMAX,RMAX)
      CALL PARAMS (4LGMIN,GMIN,4LGMAX,GMAX)
C
      XMIN=-4.0$DX=0.4$XMAX=4.0
      PSIMIN=.027$DPSI=1.0$PSIMAX=.027
      I8=8
      JDATA=JPS=JGS=0
      CALL CALPLT (0.0,0.0,-3)
      TMAJ=1.0$TMIN=0.1
      JXBCD=1HX$XHGT=4.0/15.0$JNX=-1
      XDIST=10.0$RDIST=10.0$GDIST=10.0
      JBCD(1)=1HR$JBCD(2)=1HG$JN=+1
      JSYM=0$JSIZE=1$PY=0.1
      MCURVE=11
C
620   CALL MESAGE (1,32H FN KEY 1 WILL DISPLAY PSI RANGE,32)
      CALL MESAGE (1,27H FN KEY 2 WILL COMPUTE DATA,27)
      CALL MESAGE (1,46H VARIABLES ARE XMIN,DX,XMAX,PSIMIN,DPSI,PSIMAX,4
     16)
      CALL MESAGE (1,37H FN KEY 3 WILL SCALE PSI DISTRIBUTION,37)
      CALL MESAGE (1,42H VARIABLES ARE XOR,XDV,XDIST,ROR,RDV,RDIST,42)
      CALL MESAGE (1,37H FN KEY 4 WILL PLOT  PSI DISTRIBUTION,37)
      CALL MESAGE (1,35H FN KEY 5 WILL SCALE G DISTRIBUTION,35)
      CALL MESAGE (1,31H VARIABLES ARE GOR, GDV,  GDIST,31)
      CALL MESAGE (1,35H FN KEY 6 WILL PLOT G  DISTRIBUTION,35)
      CALL MESAGE (1,44H FN KEY 7 WILL DISPLAY NON-MONOTONE VELOCITY,44)
      CALL MESAGE (1,26H FN KEY 8 WILL END PROGRAM,26)
      CALL MESAGE (1,39H FN KEY 9 WILL RETURN TO PSI RANGE EDIT,39)
      CALL MESAGE (1,25H FN KEY 10 WILL NORMALIZE,25)
      CALL MESAGE (1,38H ANY OTHER FN KEY WILL DISPLAY OPTIONS,38)
      CALL NEXT (KEY)
      IF (KEY.EQ.1) GO TO 630
      IF (KEY.EQ.2) GO TO 640
      IF (KEY.EQ.3) GO TO 810
      IF (KEY.EQ.4) GO TO 930
      IF (KEY.EQ.5) GO TO 1090
      IF (KEY.EQ.6) GO TO 930
      IF (KEY.EQ.7) GO TO 1120
      IF (KEY.EQ.8) GO TO 1170
      IF (KEY.EQ.9) GO TO 270
      IF (KEY.EQ.10) GO TO 850
      GO TO 620
C
```

```
C
C         DISPLAY  INITIAL      PSI     TABLE
630     JRT=2
        GO TO 230
C
C         COMPUTE         RADIAL      DISTRIBUTION
640     RCURVE=(PSIMAX-PSIMIN)/DPSI
        JNK1=JNK1+1
        LPLT=LPLT+1
C         CHECK     FOR     MAXIMUM    NUMBER    OF    CURVES
        IF (RCURVE.LE.FLOAT(MCURVE-1)) GO TO 660
        ENCODE (37,650,MESG) RCURVE,MCURVE
650     FORMAT (2X,F12.5,11H MORE THAN ,I5,7H CURVES)
        CALL MESAGE (4,MESG,37)
        GO TO 620
660     RPT=(XMAX-XMIN)/DX
C         CHECK     FOR     MAXIMUM    NUMBER    OF    POINTS
        IF (RPT.LE.FLOAT(MPT-1)) GO TO 680
        ENCODE (37,670,MESG) RPT,MPT
670     FORMAT (2X,F12.5,11H MORE THAN ,I5,7H POINTS)
        CALL MESAGE (4,MESG,37)
        GO TO 620
680     ICURVE=IFIX(RCURVE+1.5)
        NPT=IFIX(RPT+1.5)
        REWIND 18  $  JTONE=0
        RMAX=GMAX=-1.E9
        RMIN=GMIN=1.E9
        PSI=PSIMIN
C
C
        DO 790 J2=1,ICURVE
        GTONE=-1.E9
        IEOF=0$J3=-1
        X=XMIN
        ICODE=1
C
        DO 780 J1=1,NPT
C                   COMPUTE              RADIUS
        CALL RVALUE (ICODE)
        IF (ICODE.EQ.0) DR=R
        CALL RECOUT (18,1,IEOF,J2,J1,PSI,X,R,U,V,G)
        IF (JTONE.NE.0) GO TO 700
C         CHECK     FOR        NON-MONOTONE     VELOCITY
        IF (G.GT.GTONE) GO TO 690
        TONE(1)=J2$TONE(2)=J1$TONE(3)=PSI$TONE(4)=X
        TONE(5)=R$TONE(6)=U$TONE(7)=V$TONE(8)=G
        JTONE=1
        GO TO 700
690     GTONE=G
700     CONTINUE
C         CHECK     FOR    MINIMUM    AND     MAXIMUM   YPLOT    VALUES
```

```
      IF (R.LT.RMIN) RMIN=R
      IF (R.GT.RMAX) RMAX=R
      IF (G.LT.GMIN) GMIN=G
      IF (G.GT.GMAX) GMAX=G
      IF (IP2.NE.0) GO TO 770
      J3=J3+1
C        OUTPUT     CURVE       J2
      IF( MOD( J3, 35 ) .NE.  0  )  GO  TO   765
      PRINT 710, J2,  DATE(1),  PSIMIN,  PSIMAX,  XMIN,  XMAX
710   FORMAT (1H1//47X,34H  R AND G DISTRIBUTION  FOR CURVE ,I3,20X,4HDA
     1TE,5X,A10//20X,6HPSI = ,F14.6,5X,2HTO,F14.6,10X,3HX= ,F14.6,5X,2HT
     2O,F14.6)
      PRINT 720, PSI
720   FORMAT (5H0PSI=,F14.6)
      PRINT 730,  V1, V2,  A1,  A2,  C2,  NACC
730   FORMAT (/8X,11HINIT. VEL.=,F8.4,5X,11HFINAL VEL.=,F8.4,5X,3HA1=,F8
     1.4,5X,3HA2=,F8.4,5X,5HC**2=,F8.4,5X,2HN=,I3)
      PRINT 740,  D1, D2,  LPLT
740   FORMAT (40X,3HD1=,F8.4,5X,3HD2=,F8.4,5X,8HPLOT NO.,I5)
      PRINT 750
750   FORMAT (/13X,2HPT,14X,1HX,14X,1HR,14X,1HU,14X,1HV,14X,1HG)
  765 CONTINUE
      PRINT 760, J1,X,R,U,V,G
760   FORMAT (I15,5F15.6)
770   CONTINUE
C
      X=X+DX
      IF (X.GT.XMAX) X=XMAX
780   CONTINUE
C
      PSI=PSI+DPSI
      IF (PSI.GT.PSIMAX) PSI=PSIMAX
790   CONTINUE
C
C         DISPLAY   MINIMUM   AND   MAXIMUM   PLOT   VALUES
C
      ENCODE (80,800,MESG) RMIN,RMAX,GMIN,GMAX
800   FORMAT (6H RMIN=,F14.6,6H RMAX=,F14.6,6H GMIN=,F14.6,6H GMAX=,F14.
     16)
      CALL MESAGE (1,16H  DATA  COMPUTED,16)
      CALL MESAGE (1,MESG,40)
      CALL MESAGE (1,MESG(5),40)
      JDATA=1
      GO TO 620
C
C
810   IF (JDATA.NE.0) GO TO 820
      CALL MESAGE (2,29HCANNOT SCALE NO DATA COMPUTED,29)
      GO TO 620
C
C        COMPUTE     X   AND   R     SCALES
```

```
820   XOR=XMIN
      XDV=(XMAX-XMIN)/XDIST
      ROR=RMIN
      RDV=(RMAX-RMIN)/RDIST
      ENCODE (36,830,MESG) XOR,XDV
830   FORMAT (5H XOR=,F12.5,7H   XDV=,F12.5)
      ENCODE (36,840,MESG(6) )ROR,RDV
840   FORMAT (5H ROR=,F12.5,7H   RDV=,F12.5)
      CALL MESAGE (1,MESG,36)
      CALL MESAGE (1,MESG(6),36)
      JRS=1
      GO TO 620
C
C        NORMALIZE   LAST   MONOTONE   STREAM   LINE
850   JPLT=1
      IF (JNK1.NE.JNK2) GO TO 920
      DO 900 J1=1,NPT
      XPLOT(J1)=XPLOT(J1)/YPLOT(NPT)
      YPLOT(J1)=YPLOT(J1)/YPLOT(NPT)
      IF (MOD(J1-1,35).NE.0) GO TO 880
      PRINT 860, DATE(1)
860   FORMAT (1H1//27X,46HNORMALIZED CURVE FOR LAST MONOTONE STREAM LINE
     1,10X,4HDATE,5X,A10)
      PRINT 720, PST
      PRINT 870
870   FORMAT (//33X,2HPT,19X,1HX,19X,1HR)
880   PRINT 890, J1,XPLOT(J1),YPLOT(J1)
890   FORMAT (25X,I10,2F20.5)
900   CONTINUE
C
      ENCODE (80,910,MESG) XPLOT(1),XPLOT(NPT),YPLOT(NPT),YPLOT(1)
910   FORMAT (4H X1=,F13.6,4H X2=,F13.6,6X,4H R1=,F13.6,4H R2=,F13.6)
      CALL MESAGE (1,MESG,40)
      CALL MESAGE (1,MESG(5),34)
      CALL MESAGE (1,36H INPUT SCALE FACTORS PRESS ANY  KEY ,36)
      CALL NEXT (KEY1)
      JNK2=JNK1
920   CONTINUE
      GO TO 950
C            READ     PLOT      DATA      JPLT=1, RPLOT, JPLOT=2,GPLOT
C
930   JPLT=KEY/5+1
      IF ((JPLT.EQ.1).AND.(JRS.EQ.0)) GO TO 940
      IF ((JPLT.EQ.2).AND.(JGS.EQ.0)) GO TO 940
      GO TO 950
940   CALL MESAGE (1,39H CANNOT PLOT.  DATA HAS NOT BEEN SCALED,39)
      GO TO 620
C
950   CALL AXES (0.0,0.0,0.0,XDIST,XOR,XDV,TMAJ,TMIN,JXBCD,XHGT,JNX)
      CALL AXES (0.0,0.0,90.0,DIST(JPLT),ORG(JPLT),DV(JPLT),TMAJ,TMIN,JB
     1CD(JPLT),XHGT,JN)
```

```
      REWIND I8
      DO 990 J2=1,ICURVE
      IF ( KEY .EQ. 10 ) GO TO 970
      DO 960 J1=1,NPT
      CALL RECIN (I8,1,IC,JCV,JPT,PSI,X,R,U,V,G)
      XPLOT(J1)=X
      YPLOT(J1)=R
      IF (JPLT.EQ.2) YPLOT(J1)=G
960   CONTINUE
C
970   XPLOT(NPT+1)=XOR$XPLOT(NPT+2)=XDV
      YPLOT(NPT+1)=ORG(JPLT)$YPLOT(NPT+2)=DV(JPLT)
C                                  PLOT          DATA
      CALL LINPLT (XPLOT,YPLOT,NPT,1,JSYM,J2,JSIZE,0)
C
C          NOTATE      PLOT
      J3=17
      ENCODE (J3,980,MESG) PSI
980   FORMAT (4HPSI=,F13.6)
      PHT=0.1
      PY=FLOAT(J2-1)*(PHT+0.2)
      PX1=2.5
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,J3)
      PX=(6.0/7.0)*FLOAT(J3)*PHT+0.14-PX1
      PY=PY+0.04
      CALL PNTPLT (PX,PY,J2,1)
      IF ( KEY .EQ. 10 ) GO TO 991
990   CONTINUE
  991 CONTINUE
      ENCODE (16,1000,MESG) V1
1000  FORMAT (3HV1=,F13.6)
      PY=DIST(JPLT)-PHT
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
      ENCODE (16,1010,MESG) V2
1010  FORMAT (3HV2=,F13.6)
      PY=PY-2.0*PHT
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
      ENCODE (18,1020,MESG) C2
1020  FORMAT (5HC**2=,F13.6)
      PY=PY-2.0*PHT
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,18)
      ENCODE (16,1030,MESG) D1
1030  FORMAT (3HD1=,F13.6)
      PY=PY-2.0*PHT
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
      ENCODE (16,1040,MESG) D2
1040  FORMAT (3HD2=,F13.6)
      PY=PY-2.0*PHT
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
      ENCODE (16,1050,MESG) A1
1050  FORMAT (3HA1=,F13.6)
```

```
      PY=PY-2.0*PHT
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
      ENCODE (16,1060,MESG) A2
1060  FORMAT (3HA2=,F13.6)
      PY=PY-2.0*PHT
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
      ENCODE (14,1070,MESG) LPLT
1070  FORMAT (9HPLOT NO. ,I5)
      PY=PY-2.0*PHT
      CALL NOTATE (-PX1,PY,PHT,MESG,0.0,14)
C
      IF (JTONE.EQ.0) GO TO 1080
      IF (KEY.EQ.10) GO TO 1080
C       FLAG       NON-MONOTONE   VELOCITY    ON    PLOT
      PX=(TONE(4)-XOR)/XDV
      PY=(TONE(3*JPLT+2)-ORG(JPLT))/DV(JPLT)
      CALL PNTPLT (PX,PY,1,3)
1080  CALL CALPLT (14.0,0.0,-3)
      GO TO 620
1090  IF (JDATA.NE.0) GO TO 1100
      CALL MESAGE (3,29HCANNOT SCALE,NO DATA COMPUTED,29)
      GO TO 620
C                COMPUTE          G        SCALES
1100  GOR=GMIN
      GDV=(GMAX-GMIN)/GDIST
      ENCODE (36,1110,MESG) GOR,GDV
1110  FORMAT (5H GOR=,F12.5,7H    GDV=,F12.5)
      CALL MESAGE (1,MESG,36)
      JGS=1
      GO TO 620
1120  IF (JTONE.NE.0) GO TO 1130
      CALL MESAGE (1,23H VELOCITY  IS  MONOTONE,23)
      GO TO 620
C                DISPLAY    NON-MONOTONE       VELOCITY
1130  ENCODE (43,1140,MESG) TONE(1),TONE(2)
1140  FORMAT (7H CURVE ,F3.0,5H   PT,F4.0,22H NON-MONOTONE VELOCITY)
      CALL MESAGE (1,MESG,41)
      ENCODE (50,1150,MESG) TONE(3),TONE(4),TONE(5)
1150  FORMAT (5H PST=,F12.5,5H   X=,F12.5,4H  R=,F12.5)
      CALL MESAGE (1,MESG,50)
      ENCODE (50,1160,MESG) TONE(6),TONE(7),TONE(8)
1160  FORMAT (3H U=,F12.5,5H   V=,F12.5,6H    G=,F12.5)
      CALL MESAGE (1,MESG,50)
      GO TO 620
C
C         NORMAL     PROGRAM     STOP
1170  CALL MESAGE (4,31H REPEAT FN KEY 8 TO END PROGRAM,31)
      CALL MESAGE (4,38H ANY OTHER FN KEY WILL DISPLAY OPTIONS,38)
      CALL NEXT (KEY)
      IF (KEY.NE.8) GO TO 620
      PRINT 1180
```

```
1180  FORMAT (25H1 NORMAL  END   OF    JOB )
      STOP
      END
      SUBROUTINE STREAM
C
C       COMPUTE  VALUE  OF  THE   STREAM  FUNCTION    PSI  AT  X AND  R
C         X     =     AXIAL    COORDINATE
C         R     =     RADIAL   COORDINATE
C
      COMMON /YD2/ NACC,PSI,X,R
C
      COF(J)=(-1.0)**(J-1)*R**(2*J)/(2.0**J2*FLOAT(J)*FACT(J-1)**2)
C
      PSI=0.0
      DO 10 J1=1,NACC
      J2=2*J1-2
      PSI=PSI+COF(J1)*DERIV(J2)
10    CONTINUE
      PSI=0.5*PSI
C
      RETURN
      END
      SUBROUTINE RVALUE (ICODE)
C
C          COMPUTE     R, U, V, AND    G    FOR   PSI   AT    X
C       G   IS  THE   RESULTANT      VELOCITY
C       U   IS  THE   AXIAL     COMPONENT
C       V   IS  THE   RADIAL    COMPONENT
C         USE   INTERVAL-HALVING   METHOD
C
      COMMON /YD1/ DELR,EPS1,EPS2,MAXIT
      COMMON /YD2/ NACC,PSI,X,R,U,V,G
      COMMON /YD4/ AG1,AG2
      EXTERNAL FOFR
      COF(J)=(-1.0)**(J-1)*R**J2/(2.0**(2*J-3)*FACT(J-1)**2)
      COFF(J)=(-1.0)**(J)*R**J3/(2.0**(2*J-2)*FLOAT(J)*FACT(J-1)**2)
C
      CALL ITR2 (R,AG1,AG2,DELR,FOFR,EPS1,EPS2,MAXIT,ICODE)
      IF (ICODE.EQ.0) GO TO 10
      R=U=V=G=-999.0
      RETURN
C
10    U=V=0.0
      DO 40 J1=1,NACC
      J2=2*J1-2
      J3=2*J1-1
C
C
      IF ((J2.NE.0).OR.(ABS(R).GT.1.E-12)) GO TO 20
      U=2.0*DERIV(J2)
      GO TO 30
```

```
20    CONTINUE
      U=U+COF(J1)*DERIV(J2)
30    CONTINUE
      V=V+COFF(J1)*DERIV(J3)
40    CONTINUE
      U=0.5*U
      V=0.5*V
C
C
      G=SQRT(U**2+V**2)
      RETURN
      END
      FUNCTION FACT (J)
C
C       FACTORIAL    FUNCTION
      FACT=1.0
      IF  (J.EQ.0)  RETURN
      IF  (J.EQ.1)  RETURN
C
      DO 10 J1=2,J
      FACT=FACT*FLOAT(J1)
10    CONTINUE
      RETURN
      END
      FUNCTION FOFR (R)
C          EVALUATE    FUNCTION   FOR    IT-2
      COMMON /YD2/ NACC,PSI,X,RR
C
      SAV1=PSI
      RR=R
      CALL STREAM
      FOFR=PSI
      PSI=SAV1
      FOFR=PSI-FOFR
      RETURN
      END
      FUNCTION DERIV (J)
      COMMON /YD2/ NACC,PSI,X
      COMMON /YD3/ A1,A2,C2,D1,D2
      DIMENSION HERM(50), HER(50), FOFX(1), ANS(1)
      EXTERNAL FUNC
C
C          COMPUTE    JTH DERIVATIVE    OF    VELOCITY    FUNCTION
      SR=SQRT(2.0*3.14159265)
      EX=EXP(-C2*X**2)/SR
      EX1=EXP(-X**2)
      HERM(1)=EX
      HERM(2)=-2.0*C2*X*HERM(1)
      HER(1)=1.0
      HER(2)=2.0*X
      HER(3)=4.0*X**2-2.0
```

```
      HER(4)=8.0*X**3-12.0*X
C
C
      IF (J.NE.0) GO TO 20
      RL1=0.0$RL2=X
      IF (RL2.GT.RL1) GO TO 10
      RL1=X$RL2=0.0
10    CONTINUE
      CALL MGAUSS (RL1,RL2,10,ANS,FUNC,FOFX,1)
      DERIV=A1+SIGN(1.0,X)*A2*ANS+EX1*(D1*HER(1)+D2*HER(2))
      RETURN
C
20    IF (J.NE.1) GO TO 30
      DERIV=A2*FX-EX1*(D1*HER(2)+D2*HER(3))
      RETURN
C
30    IF (J.NE.2) GO TO 40
      DERIV=-2.0*A2*C2*X*EX+EX1*(D1*HER(3)+D2*HER(4))
      RETURN
C
40    HER(J+1)=2.0*X*HER(J)-2.0*FLOAT(J-1)*HER(J-1)
      HER(J+2)=2.0*X*HER(J+1)-2.0*FLOAT(J)*HER(J)
C
      IF (J.EQ.3) GO TO 50
      HERM(J-1)=-2.0*C2*(X*HERM(J-2)+FLOAT(J-3)*HERM(J-3))
50    HERM(J)=-2.0*C2*(X*HERM(J-1)+FLOAT(J-2)*HERM(J-2))
      S1=1.0
      IF (MOD(J,2).NE.0) S1=-1.0
      DERIV=A2*HERM(J)+S1*EX1*(D1*HER(J+1)+D2*HER(J+2))
      RETURN
      END
      SUBROUTINE FUNC (X,FOFX)
      DIMENSION FOFX(1)
      COMMON /YD3/ A1,A2,C2
C         EVALUATE  VELOCITY  FUNCTION  FOR  MGAUSS
      SR=SQRT(2.0*3.14159265)
      FOFX=EXP(-C2*X**2)/SR
      RETURN
      END
```

REFERENCES

1. Tsien, Hsue-Shen: On the Design of the Contraction Cone for a Wind Tunnel. J. Aeronaut. Sci., vol. 10, no. 2, Feb. 1943, pp. 68-70.
2. Cohen, M. J.; and Ritchie, N. J. B.: Low-Speed Three-Dimensional Contraction Design. J. Royal Aeronaut. Soc., vol. 66, no. 616, Apr. 1962, pp. 231-236.
3. Szczeniowski, Boleslaw: Contraction Cone for a Wind Tunnel. J. Aeronaut. Sci., vol. 10, no. 8, Oct. 1943, pp. 311-312. (Errata issued, vol. 11, no. 2, Apr. 1944, p. 173.)
4. Thwaites, B.: On the Design of Contractions for Wind Tunnels. R. & M. No. 2278, Brit. A.R.C., 1946.
5. Bossel, Hartmut H.: Computation of Axisymmetric Contractions. AIAA J., vol. 7, no. 10, Oct. 1969, pp. 2017-2020.
6. Courant, R.; and Hilbert D.: Methods of Mathematical Physics. Vol. I. Interscience Publ., Inc., c.1953, p. 91.
7. Morse, Philip M.; and Feshbach, Herman: Methods of Theoretical Physics. Pt. I. McGraw-Hill Book Co., Inc., 1953, p. 786.

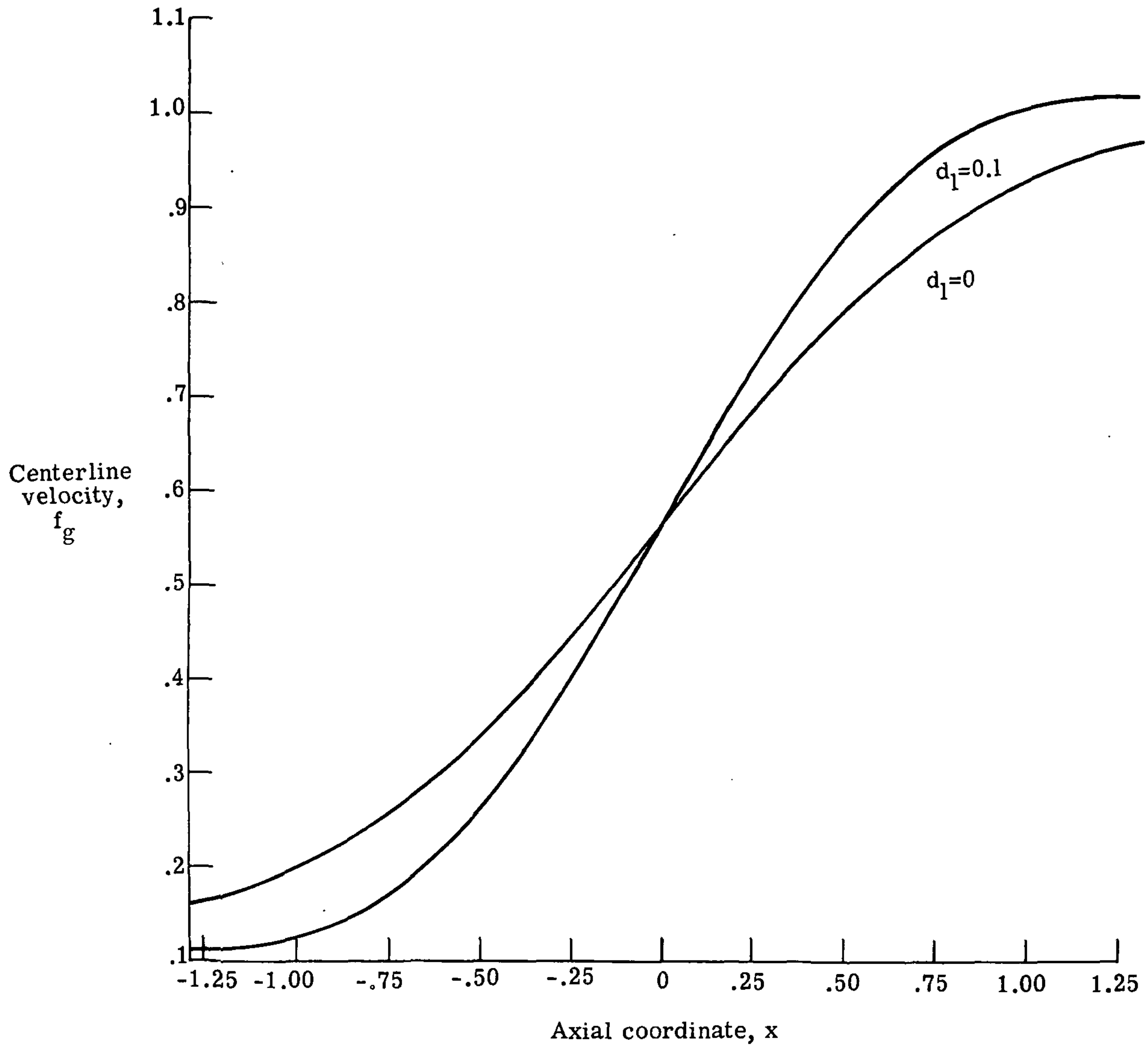

Figure 1.- Axial velocity used for contraction-cone design $(d_1 = 0.1)$ compared with that obtained with $d_1 = 0$. Nonzero parameters: $A = 0.5665$; $B = 0.4335$; $c = 1$.

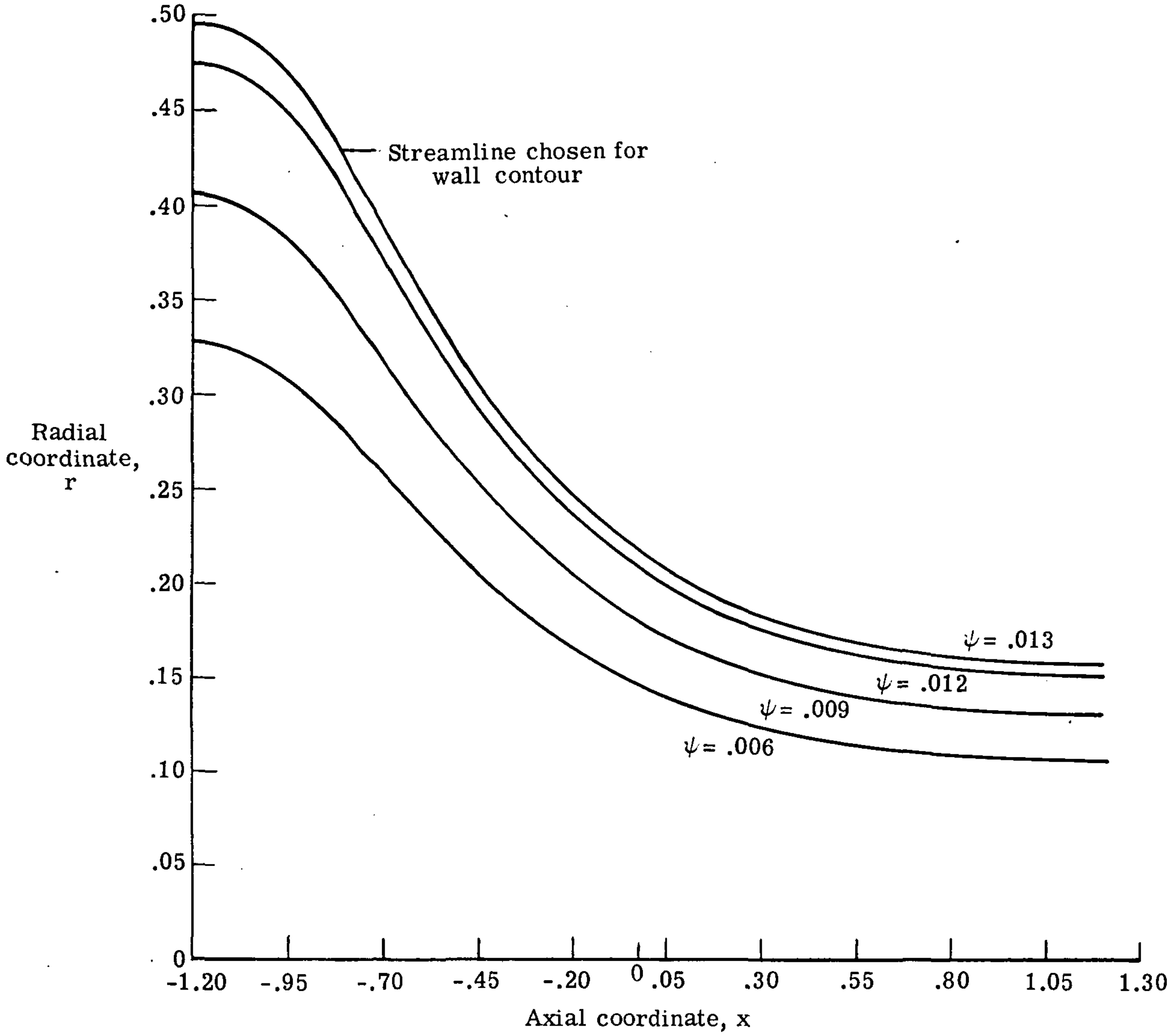

Figure 2.- Coordinates of wall contour and some streamlines for design velocity of figure 1.

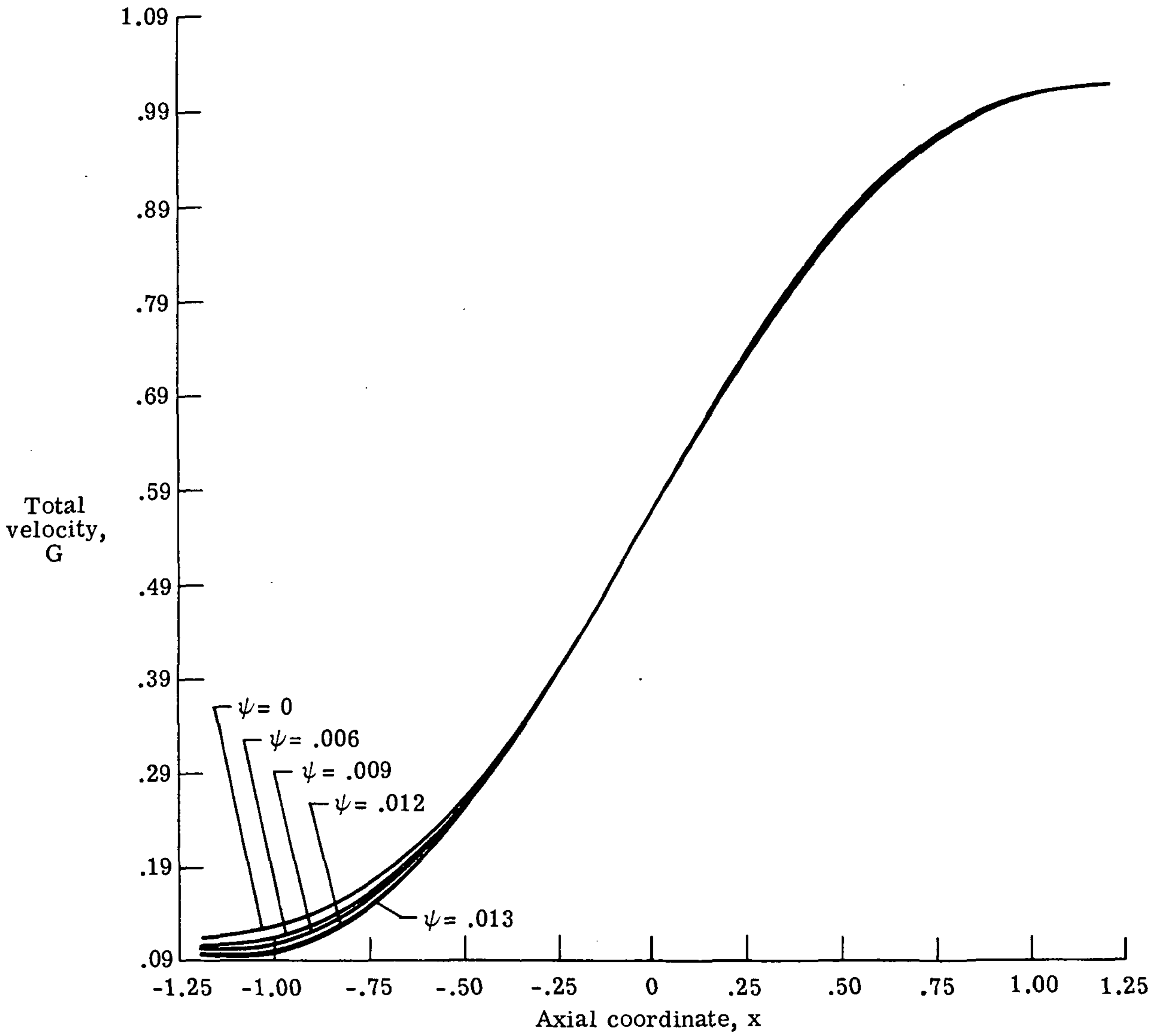

Figure 3.- Velocity distributions along centerline, wall, and streamlines of figure 2.

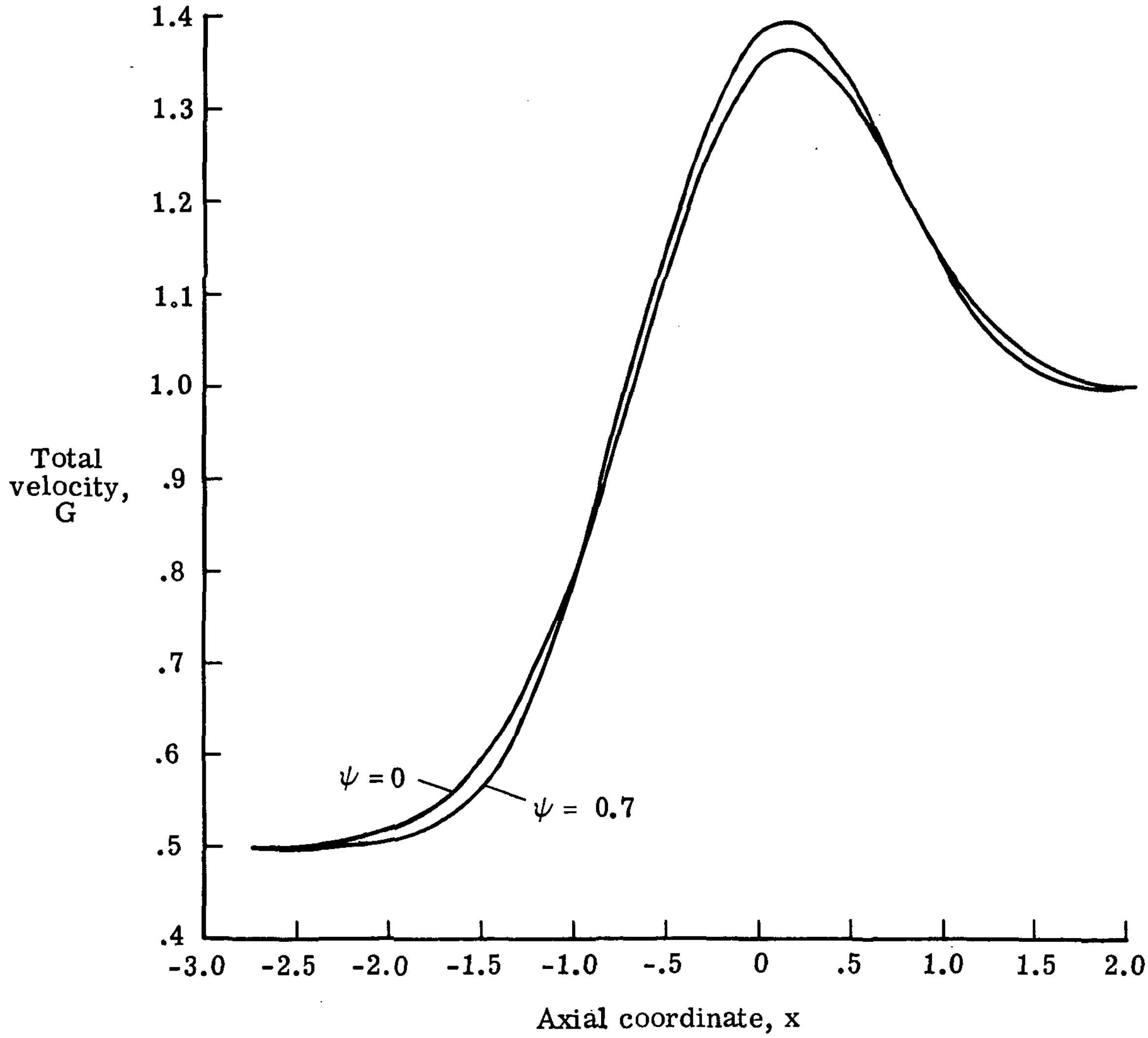

Figure 4.- Design (centerline) and wall velocity distribution for duct with an area minimum. Nonzero parameters: $A = 0.75$; $B = 0.25$; $d_0 = 0.6$; $c^2 = 0.5$.

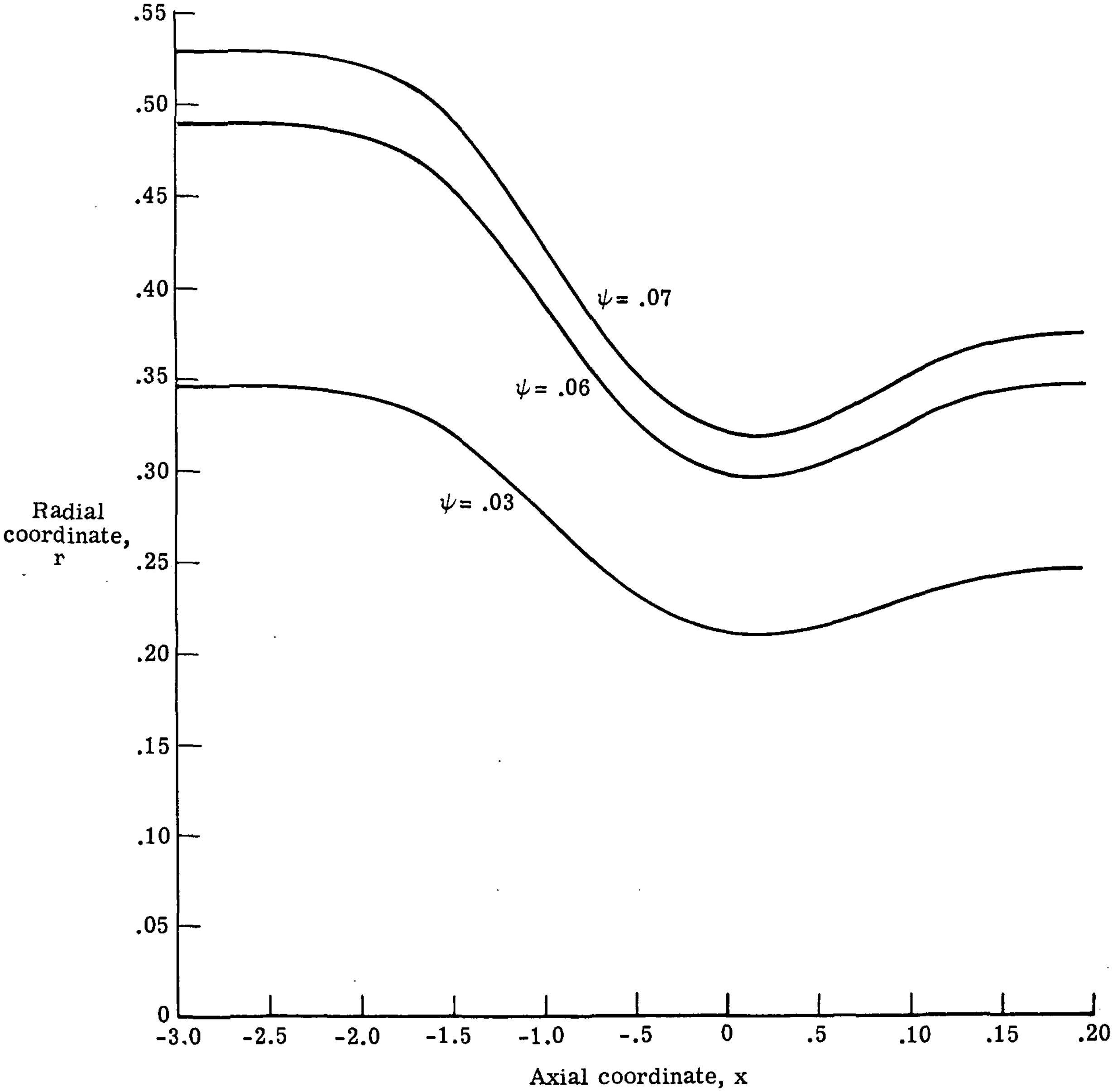

Figure 5.- Wall contour and some streamlines for the design velocity of figure 4.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546